Spring 2003

UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Electrical Engineering and Computer Sciences

EE143 Midterm Exam #1

Family Name ______________________ **First name**__________________________

Signature____

Make sure the exam paper has 7 pages + 3 pages of data for reference

Instructions: DO ALL WORK ON EXAM PAGES
This is a 90-minute exam (4 sheets of notes allowed)

Grading: To obtain full credit, show correct units and algebraic sign in answers. Numerical answers which are orders of magnitude off will receive no partial credit.

Problem 1 (20 points)_______________

Problem 2 (25 points)______________

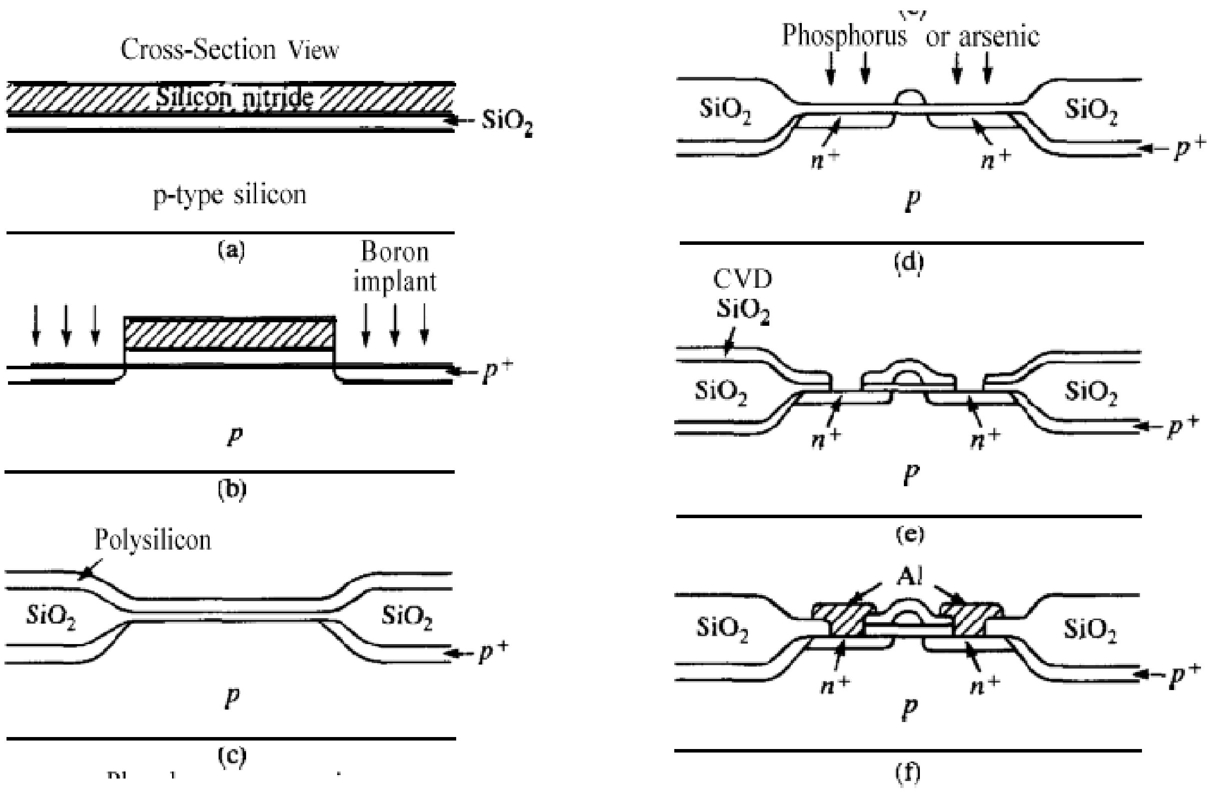
Problem 3 (30 points) _______________

Problem 4 (25 points) _______________

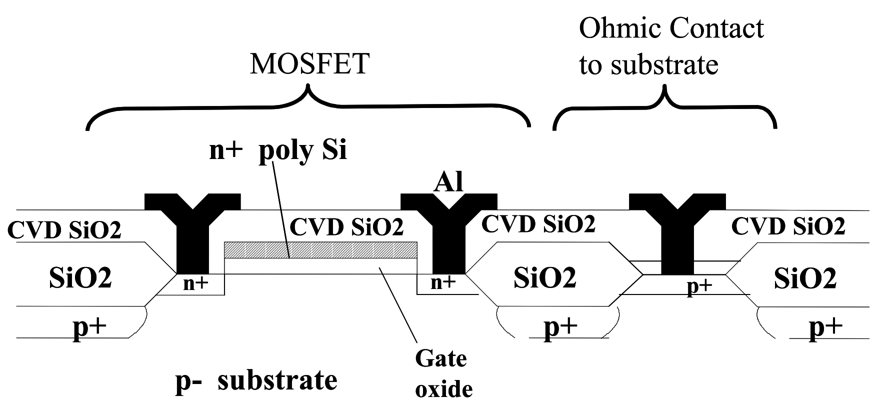
TOTAL (100 points) _________________

Problem 1 Simple Process Sequence (20 points total)

The following process sequence and cross-sections are taken from Chapter 1 of the EE143 textbook by Jaeger on fabricating a N-channel MOS transistor.

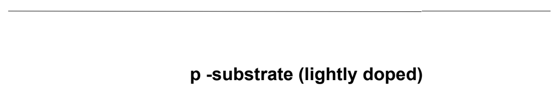


(a) (5 points) Suppose we would like to **add** an ohmic contact structure to the p-substrate (see schematic below) so that the substrate can be biased at various voltages. How many **additional** lithography masks will be needed ? Briefly describe the function of the extra mask(s).

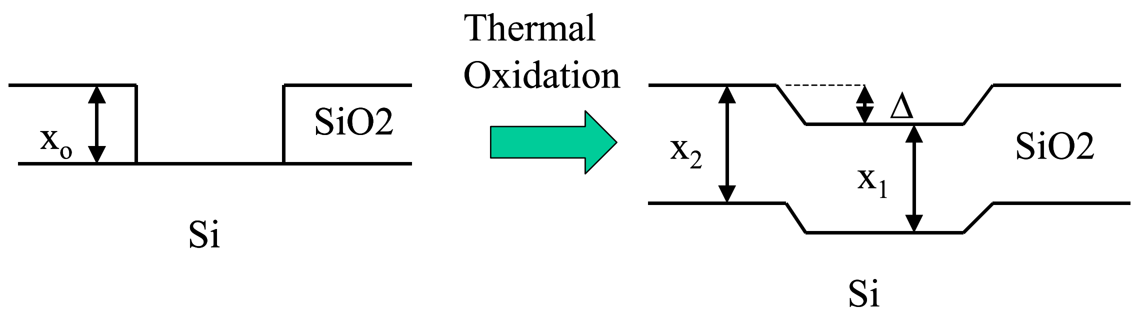


Problem 1 continued

(b) (15 points) Modify the MOSFET process sequence so that one can fabricate **both** the MOSFET and ohmic contact structures. Describe the process steps in the left column and show the cross-sections (with both MOSFET and ohmic contact components) in the right column,

Process Description	Cross Section
1) Starting wafer, p- Si	

Problem 2 Thermal oxidation (25 points total)
We are interested in the oxide thickness difference (x_2-x_1) after thermal oxidation of an oxide window on a Si wafer.



(a) (4 points) Use the Deal-Grove Model result $x_{ox}^2 + A\,x_{ox} = B\,(t + \tau)$ to show that :

$$(x_2 - x_1) = x_o \bullet \frac{A + x_o}{A + x_1 + x_2}$$

(b) (3 points) Can ($x_2 - x_1$) be larger than x_o? Explain.

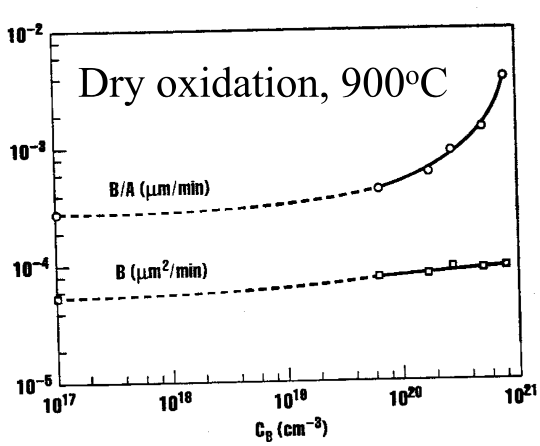
(c) (3 points) For very long oxidation time ($t \rightarrow \infty$), what will be the value of ($x_2 - x_1$) ?

(d) (3 points) Expressed the surface oxide step height Δ in terms of x_o, x_1, and x_2.

(e) (8 points) By maintaining other variables the same , how will an increase of the following parameter affect the value of the surface height difference (Δ) in the following table. Use "+" to represent increase, "-" to represent decrease, and "0" to represent no change.

	Effect on Δ	**Brief Explanation**
Initial oxide thickness x_o ↑		
Oxidation time t ↑		
Oxidation temperature ↑		
Oxidant gas pressure ↑		

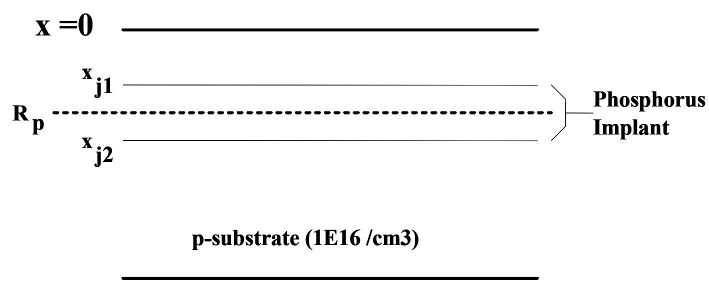
(f) (4 points) Use charged vacancy concentration to explain why the B/A term increases rapidly with doping concentrations above $10^{19}/cm^3$.



Problem 3 Ion Implantation (30 points total)

(A)

(a) (4 points) Phosphorus is implanted into a p-Si with a uniform background concentration of $10^{16}/cm^3$. The Phosphorus (P+) dose is $10^{13}/cm^2$ and the energy used is 200 keV. Find the sheet resistance of the phosphorus implanted layer using $R_s \approx 1/(q\mu\phi)$.



(b) (4 points) Find the junction depths x_{j1} and x_{j2} formed by the Phosphorus implantation.

(c) (3 points) After phosphorus implantation, a thermal annealing step is carried out with a Dt product of 10^{-12} cm^2 to restore the crystalline damage and to activate the dopants. You find the implanted profile does not change much. Explain.

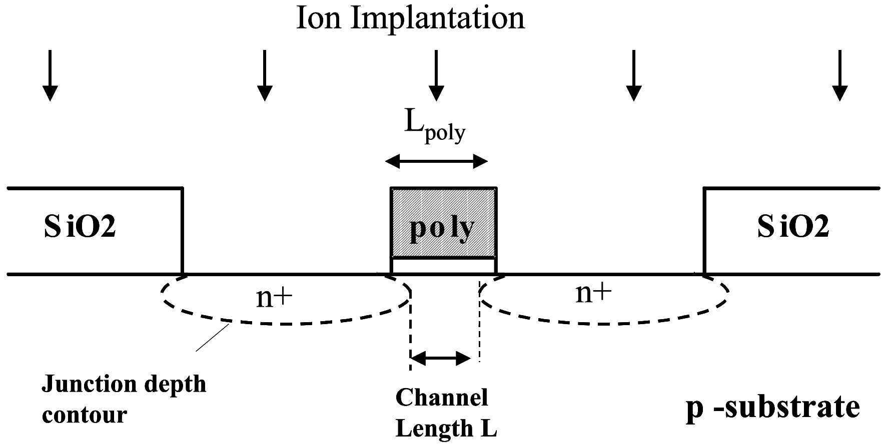
(d)(3points) Poly-Si (thickness = 0.5 μm) is then deposited on top of the Si substrate described in part (c), followed by a Boron (B+) implantation step. The Boron energy is chosen such that the **Boron peak position coincides with the Phosphorus peak position in the Si substrate**. What is the chosen boron (B+) ion energy (in keV) ?

(e) (3 points) For conditions used in part (d), the Boron (B+) dose is chosen such that **the boron peak concentration is equal to the phosphorus peak concentration .** What is the chosen boron (B+) dose ?

(f) (5 points) Sketch qualitatively the **hole concentration** versus depth after both phosphorus and boron implantations in a semilog plot.

Problem 3 continued

(B) (5 points) Arsenic implant is used to form the source/drain of a MOSFET. Consider the following structure where both SiO_2 and poly-Si are sufficiently thick to block out all vertical implantation profiles. However, the **lateral straggle** ΔR_t of implantation will reduce the channel length (L) of MOSFETs.:



Indicate in the following table whether the channel length L will increase (↑) , decrease, (↓) , or not changed (0) when one of the parameters changes while the others remain constant.

Parameter	Channel Length L
Implant Dose ↑	
Substrate conc. N_B ↑	
Polysilicon (poly) thickness ↑	
Arsenic ion energy ↑	
Implant ions changed from Arsenic to Phosphorus (same ion energy)	

(C) (3 points) Even we tilt and rotate the Si wafer to avoid direct channeling during implantation, we still obtain an small anomalous channeling tail . Why ? How can one eliminate this anomalous channeling tail in the implant profile.

Problem 4 Diffusion and Sheet Resistance (25 points total)

(A) A Boron ***drive-in*** step gives a half-gaussian depth profile. The n-type Si wafer has a background concentration = $4 \times 10^{15}/cm^3$. The drive-in profile has a surface concentration of $5 \times 10^{18}/cm^3$ and a junction depth of 4 μm.

(a) (3 points) Calculate the Dt product of the drive-in profile ?

(b) (3 points) Use the Irvins curves to find the sheet resistance of the boron diffused layer ?

(c) (3 points) What is the boron dose in the diffused layer ?

(B) Suppose the boron dose in part (A) was introduced by solid-solubility-limited diffusion (i.e. the ***predeposition*** process) prior to the drive-in step.
(a)(6 points) You have to choose either a 1000°C or a 900°C predeposition temperature. Which temperature will you choose and explain why ? Justify your answer quantitatively.

Given : Solid solubility of boron (1000C) =1 x $10^{21}/cm^3$
Solid solubility of boron (900C) = 5.5 x $10^{20}/cm^3$
Diffusion constant of boron D = 10.5 exp (-3.69 eV/ kT) cm^2/sec

(b) (4 points) Calculate the junction depth with the predeposition conditions you choose in part(a).

(C) (6 points) Considering **high-concentration diffusion effects** of dopants in Si.
(i) Do you think the junction depth of the boron drive-in step in Part (A) will be larger, smaller, or no change? Explain.

(ii) Do you think the junction depth of the boron predeposition step in Part(B) will be larger, smaller, or no change ? Explain.

Information for reference

Electron charge $q = 1.6 \times 10^{-19}$ coulombs; Boltzmann constant $k = 8.62 \times 10^{-5}$ eV/K

n_i of Si $= 3.69 \times 10^{16} \times T^{3/2} \exp[-0.605\text{eV}/kT]$ cm^{-3}

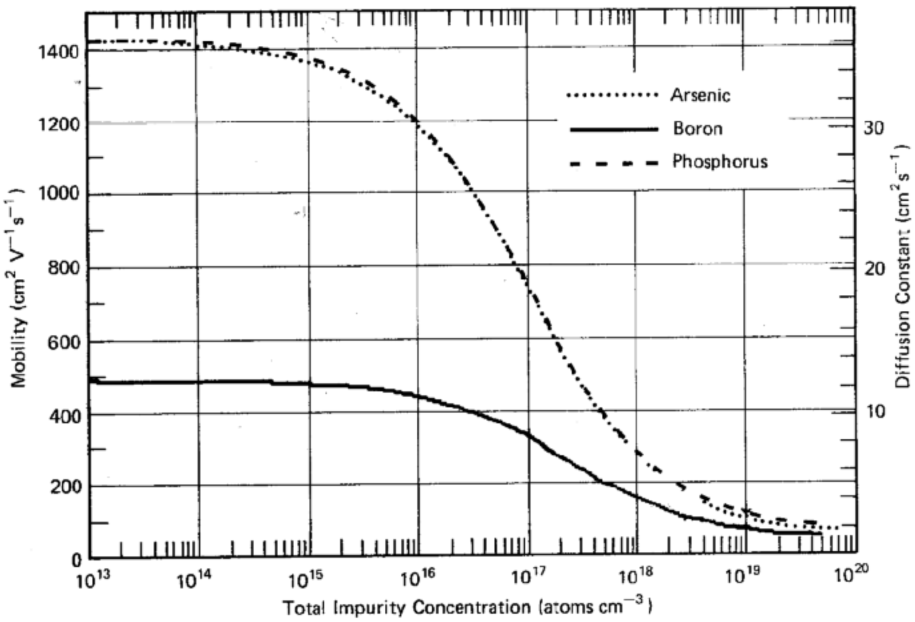
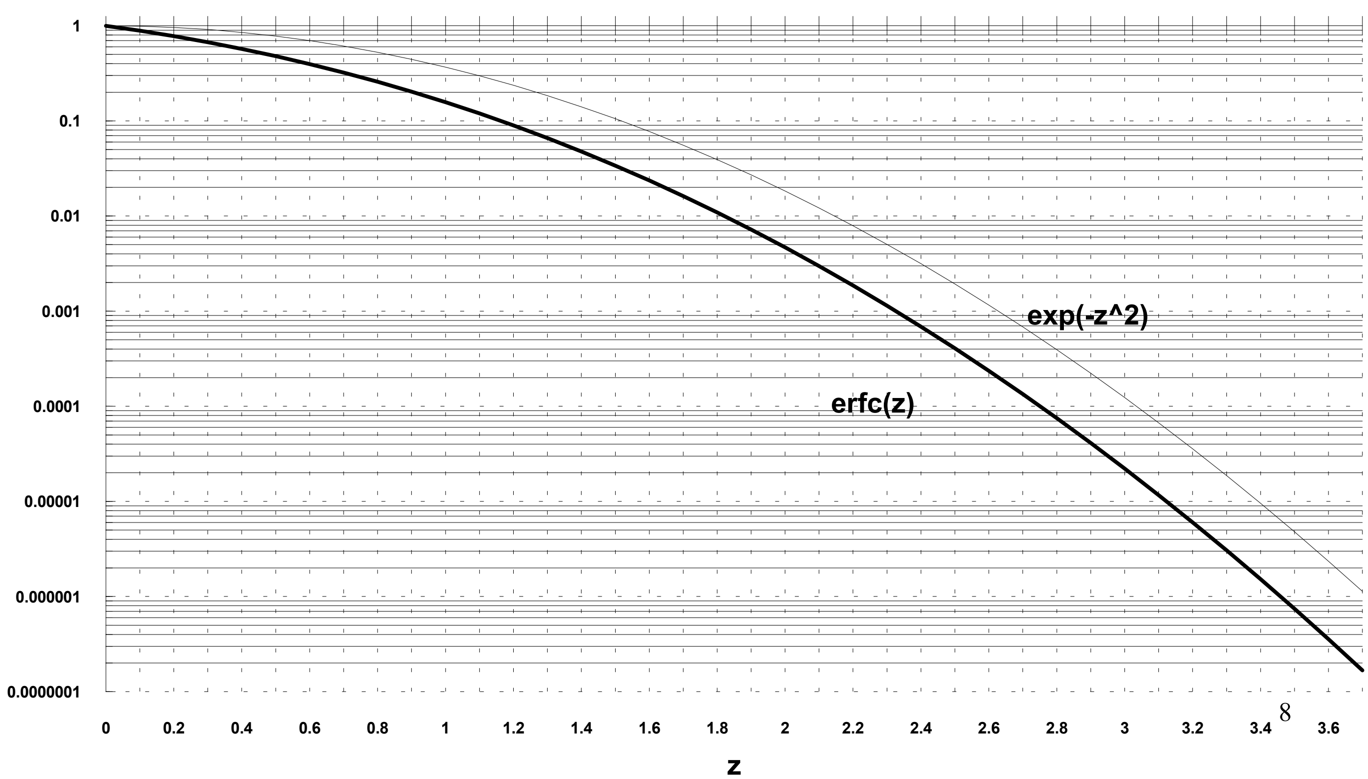
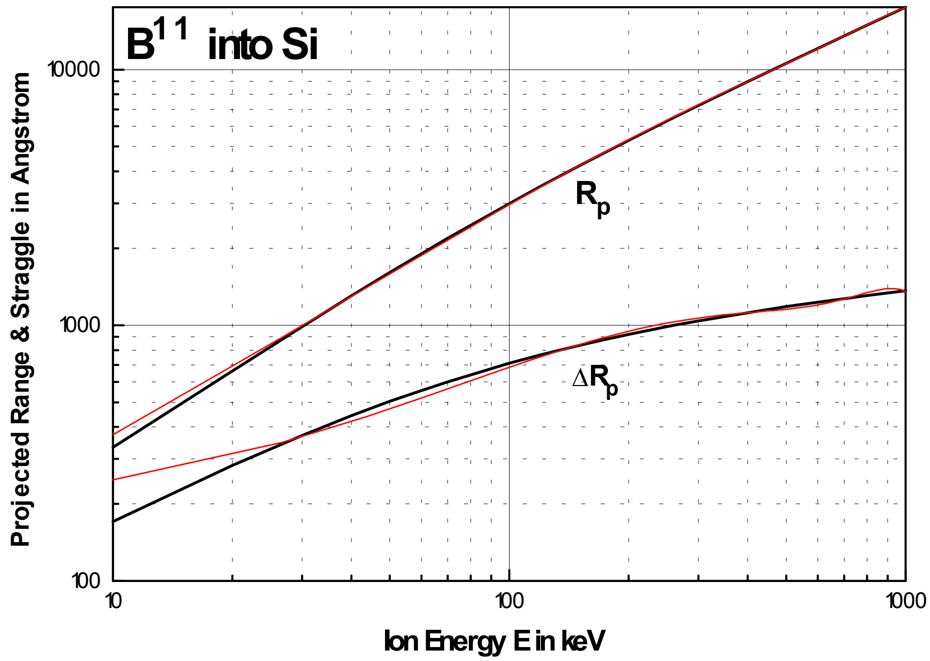


Figure 1.15 Electron and hole mobilities in silicon at 300 K as functions of the total dopant concentration. The values plotted are the results of curve fitting measurements from several sources. The mobility curves can be generated using Equation 1.2.10 with the following parameter values:[3]



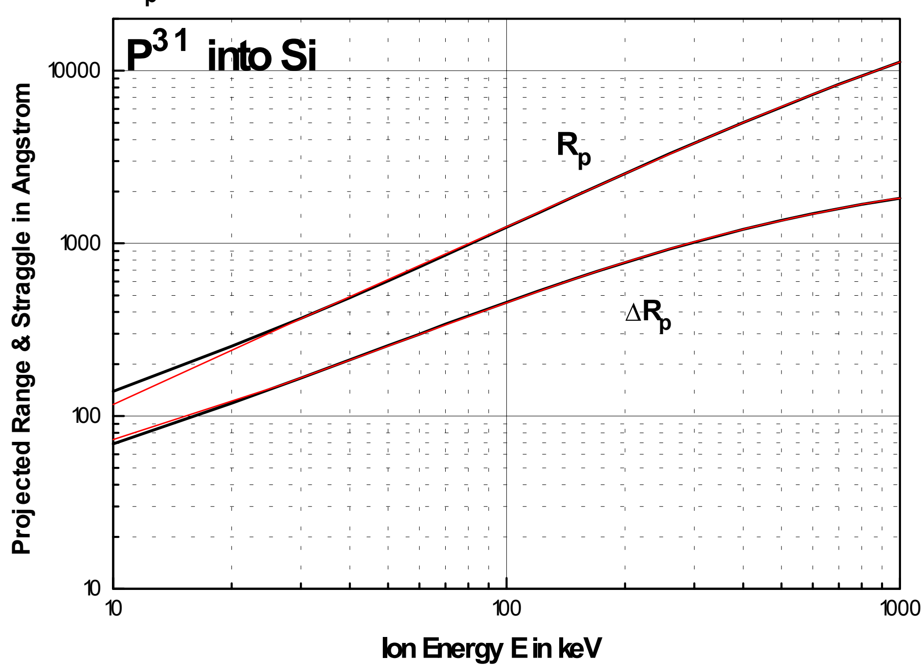
$$R_p=51.051+32.60883\,E-0.03837\,E^2+3.758e\text{-}5\,E^3-1.433e\text{-}8\,E^4$$

$$\Delta R_p=185.34201+6.5308\,E-0.01745\,E^2+2.098e\text{-}5\,E^3-8.884e\text{-}9\,E^4$$



$$R_p=-7.14745+12.33417\,E+0.00323\,E^2-8.086e\text{-}6\,E^3+3.766e\text{-}9\,E^4$$

$$\Delta R_p=24.39576+4.93641\,E-0.00697\,E^2+5.858e\text{-}6\,E^3-2.024e\text{-}9\,E^4$$



Irvin Curves